SUGGESTIONS CONCERNING THE TERMINOLOGY OF SOIL BACTERIA

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The period 1890–1910 has been one of notable progress in soil bacteriology. It is marked, on the one hand, by the appearance of KRAMER's book[1] and, on the other, by the publication of LÖHNIS' handbook.[2] A comparison of these two works will show not only a rapid increase in the body of facts relating to soil bacteria, but also a series of more or less successful attempts to arrange these facts in an orderly fashion. There have been created in this manner a number of terms that are to designate certain groups of physiological functions or reactions, like nitrogen-fixation, nitrification, denitrification, sulphate-reduction, etc.

As we inquire into the meaning of the different terms thus created, we find much that is indefinite and confused. We find, likewise, that other terms, while definite enough as to their meaning, are too unwieldy for use in the lecture room. For instance, the term "denitrification," already well established in our terminology, is not at all definite. The earlier investigators employed it to designate the reduction of nitrates,[3] irrespective of the fact whether the reduction products were nitrites, ammonia, nitrous oxide, or nitrogen gas. Latterly there has been a tendency to restrict the use of the term to the complete reduction of nitrates, involving the liberation of nitrogen gas, or at most of nitrous and nitric oxides. KAYSER[4] and after him LÖHNIS[5] have attempted to distinguish between complete and partial reduction of nitrates by employing the terms "direct denitrification" and "indirect denitri-

[1] Die Bakteriologie in ihren Beziehungen zur Landwirtschaft. Vol. 1. Wien. 1890.

[2] Handbuch der landwirtschaftlichen Bakteriologie. Berlin. 1910.

[3] GAYON and DUPETIT, Recherches sur la réduction des nitrates par les infiniment petits. Station Agronomique de Bordeaux. Nancy. 1886.

[4] Microbiologie Agricole, p. 117.

[5] Handbuch der landwirtschaftlichen Bakteriologie, p. 447.

fication." It is needless to say that these terms are not only too long, but when taken together with "Nitratreduktion" and "Salpeterassimilation," as employed by LÖHNIS,[6] they are far from removing the existing confusion.

In the same way the terminology relating to the formation of nitrogen compounds by microorganisms out of elementary nitrogen is not at all satisfactory. The terms "Stickstofffixierung," "Stickstoffsammlung," and "Stickstoffassimilation" are used interchangeably in the German publications. The English terminology, with its "nitrogen-fixing," "nitrogen-gathering," and "nitrogen-assimilating" bacteria, is as unwieldy as the German "Stickstofffixierende Bakterien," or the French "microbes fixateurs d'azote." To make matters worse, there has crept into American publications[7] the use of "nitrification" and "nitrifying" as synonymous with "nitrogen-fixation" and "nitrogen-fixing," respectively.

Almost as much confusion exists in the designation of other physiological reactions. One is uncertain in these days whether "methane bacteria" are organisms capable of decomposing cellulose with the formation of methane, or are merely organisms capable of oxidizing methane to water and carbon dioxide. It is difficult to decide, at times, whether the term "sulphur bacteria" refers to the organisms capable of oxidizing hydrogen sulphide partly, or to those capable of oxidizing it completely. Other examples of indefiniteness or confusion may be found in the terminology of sulphate reduction, hydrogen formation and oxidation, and ammonia production and transformation.

The foregoing examples will suffice to show that there is need for more rigid definition and classification in the domain of soil bacteriology. Indeed, this need is so pronounced that the writer has been led to prepare the present paper in spite of his desire not to introduce striking innovations, and in spite of the knowledge that any proposed change in the terminology already existing will be criticized. The writer would add here, however, that it is not his intention to propose any change either morphological or physiological in the general classification of bacteria. It is his wish,

[6] *Op. cit.*, pp. 477–478.

[7] See FLETCHER, "Soils."

merely, to systematize the designations of certain types of physiological reactions, and to arrange them so as to provide for future development. In doing this he has found it necessary to create a few new terms and to modify the meaning of old terms. The proposed arrangement of some of the more important groups of soil bacteria is as follows:

GROUPS OF SOIL BACTERIA ARRANGED IN ACCORDANCE WITH THEIR PHYSIOLOGICAL FUNCTIONS

Ammono-bacteria	*De-ammono-bacteria*
amino-	-amino
pepto-	-pepto
proteo-	-proteo
	-nitri
	-nitra
Nitro-bacteria	*De-nitro-bacteria*
nitri-	-nitri
nitra { ammono-	-ammono
nitri-	-nitrioxy
	-nitraoxy
Proteo-bacteria	*De-proteo-bacteria*
ammono-	-pepto
amino-	-amino
pepto-	-ammono
proteo-	
nitri-	
nitra-	
Azoto-bacteria	*De-azoto-bacteria*
azo-	amino-azo
rhizo-	ammono-azo
	nitra-azo
	nitri-azo
Sulpho-bacteria	*De-sulpho-bacteria*
sulphid-	-sulphite
thio-	-sulphid
Ferri-bacteria	
ferro-	

DEFINITIONS

Ammono-bacteria.—Organisms capable of producing ammonia out of nitrogen compounds.

Nitro-bacteria.—Organisms capable of oxidizing nitrogen compounds to nitrites, nitrates, or both.

Proteo-bacteria.—Organisms capable of transforming nitrogen compounds into protein.

Azoto-bacteria.—Organisms capable of changing elementary into combined nitrogen.

De-ammono-bacteria.—Organisms capable of transforming ammonia into nitrogen compounds other than nitrites or nitrates.

De-nitro-bacteria.—Organisms capable of reducing nitrates to nitrites, ammonia, nitrous or nitric oxide.

De-proteo-bacteria.—Organisms capable of transforming protein into more simple cleavage products.

De-azoto-bacteria.—Organisms capable of liberating elementary nitrogen from nitrogen compounds.

Sulpho-bacteria.—Organisms capable of oxidizing hydrogen sulphide to elementary sulphur, sulphites, or sulphates.

De-sulpho-bacteria.—Organisms capable of reducing sulphates to sulphites or sulphides.

Ferri-bacteria.—Organisms capable of transforming ferrous into ferric compounds.

CORRESPONDING TERMS

Ammonification	Deammonification
Nitrification	Denitrification
Proteofication	Deproteofication
Azotofication	Deazotofication
Sulphofication	Desulphofication
Ferrification	Deferrification

Of the eleven groups of bacteria named above, eight consist of organisms concerned in the transformation or increase of combined nitrogen. The ammono-bacteria consist of amino-ammono, pepto-ammono, and proteo-ammono, according to the source of the ammonia. It will be noted that the first part of the combined term refers to the initial product and the second part to the final product. Thus, proteo-ammono-bacteria are organisms capable of forming ammonia out of protein. It is evident, of course, that a single organism may be able to produce ammonia out of both peptone and protein, and it could be designated, therefore, as pepto-ammono and likewise as proteo-ammono. Similarly, the nitro-bacteria include the nitri- and the nitra-bacteria. The latter in their turn may consist of ammono-nitra and nitri-nitro, the assumption being in this case that there are species capable of oxidizing ammonia directly to nitrates.

The proteo-bacteria would naturally include a large number of species, among them the nitrate, ammonia, and amino assimilating species. While objections will probably be raised against the creation of this very general group, it must be recognized that the terms ammono-proteo or nitra-proteo are more consistent than "nitratassimilierende" or "ammonassimilierende." Moreover, these terms should supplement the term "proteofication," a very compact and logical designation of the transformation of various nitrogen compounds into protein.

The azoto-bacteria should include all of the nitrogen-fixing species. According to the proposed terminology, they would consist of the azo-bacteria, that is, the non-symbiotic nitrogen-fixing bacteria (freilebende stickstofffixierende Bakterien) and the rhizo-bacteria, that is, *Ps. radicicola*. The azo-bacteria would in their turn consist of *Clostridium Pastoriannum*, *Azotobacter*, and miscellaneous species already known or still to be discovered. The proposed classification is elastic enough to allow the presence in the azo group of azo-ammono- or azo-nitro-bacteria, should it ever be definitely shown that elementary nitrogen may be directly transformed by certain species into ammonia or nitrate. No serious objection should be raised against the proposed use of azoto, azo, and rhizo. They are not only an improvement on the unwieldy terms at present in use, but are quite in keeping with the term azotofication, whose acceptability will hardly be disputed.

Turning now to the terms de-ammono, de-nitro, de-proteo, and de-azoto, we find them to be the opposites of the corresponding ammono, nitro, proteo, and azoto. Just as ammono designates the *appearance* of ammonia, so de-ammono designates the *disappearance* of ammonia. Now ammonia may disappear by being converted into amino-compounds, peptone, or protein; hence, de-ammono-amino, de-ammono-pepto, de-ammono-proteo. Also in this, as in every other case, the first part of the compound term designates the initial and the second part the final product. The terms de-ammono-nitri and de-ammono-nitra were not included in this group, because they properly belong to the nitro group (ammono-nitri and ammono-nitra).

The meaning of de-nitro has been modified to correspond to

nitro. It will be remembered that nitrifying bacteria, according to the accepted definition, are organisms capable of changing ammonia into nitrites and nitrates. If it be true, as it is claimed by KASERER, that there are organisms capable of oxidizing elementary nitrogen directly to nitrates, they should be included under the azoto-bacteria, the true nitrogen-fixing bacteria. Hence, nitrification deals properly with the transformation of nitrogen compounds, more strictly speaking, the *oxidation* of combined nitrogen. Now, since *denitrification* is a *reduction of combined nitrogen*, it should not include processes where *elementary* nitrogen is formed. The latter are the opposite of azotofication (nitrogen-fixation), and should therefore be included under deazotofication. In other words, KAYSER'S and LÖHNIS' direct *denitrification* would become deazotofication under the proposed terminology, and their indirect denitrification would properly become denitrification. The advantages of the proposed arrangement are so evident that further discussion is hardly necessary.

The next group of de-proteo-bacteria would naturally include the organisms of decay and putrefaction, and the term employed here should therefore refer to dissimilation processes. It is evident at the same time that many de-proteo-bacteria would also be proteo-bacteria and *vice versa*. Objection may be raised for this reason to de-proteo, as well as to proteo; nevertheless, because of their supplementing the very convenient terms proteofication and deproteofication, they should be retained.

The group of de-azoto-bacteria would include all species capable of breaking down nitrogen compounds with the evolution of elementary nitrogen. Starting with amino-compounds, ammonia, nitrates, or nitrites, we could have amino-azo-, ammono-azo-, nitra-azo-, and nitri-azo-bacteria. As was already indicated above, the direct denitrifiers would be designated here as nitri-azo- or nitra-azo-bacteria. Similarly, the organisms capable of oxidizing ammonia with the evolution of elementary nitrogen would be designated as ammono-azo-bacteria.

We come finally to the sulpho-bacteria and de-sulpho-bacteria, organisms concerned with the oxidation of hydrogen sulphide and elementary sulphur on the one hand, and of reducing sulphates

and sulphites on the other. The method of classification has been sufficiently outlined above to make it unnecessary to go into further detail here. It should be pointed out, however, that the proposed terminology could be extended to embrace many other physiological functions and reactions. It would be made to include the appearance and disappearance of methane, of hydrogen, of carbon monoxid, of sugars, amino-compounds, alcohols, organic acids, etc. Terms like dextro-propio or dextro-butyro should not be difficult to understand, nor many other compound terms that will readily suggest themselves to the reader.

The writer is aware of imperfections existing in the proposed grouping of some of the species; he feels, however, that in spite of these imperfections his suggestions deserve careful consideration at the hands of his colleagues. Should the present paper do no more than create a critical discussion of the existing terminology his work will not have been in vain.

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